

## Modeling Multiple HF Antennas on the C-130/Hercules Aircraft – Part I

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### Abstract

Transport aircraft such as the C-130/Hercules need a long range HF communications system. There is also an interest in dual HF systems using two separate antennas, in a SIMOP mode: one transmitting and the other receiving, at arbitrary frequencies over the 2-30 MHz HF frequency range. Candidates for these HF antennas are probes on the vertical stabilizer or the wingtips and dorsal or wing-root notch antennas. This paper reports on the computer modeling of these candidate antennas with NEC4 and the Galerkin MBC computer code. In this initial paper, the comparative results are presented for the impedance of each antenna and for the classic ‘HF Performance Parameters’, from spectral sweeps carried out in 0.1 MHz steps over the entire HF band. At selected frequencies, current distributions and volumetric radiation patterns are presented in order to understand the peaks and variations in the plots of impedance and in the performance parameters. Appreciation of performance of the candidate antennas is an essential first step. The current distributions on the model for each antenna begin to indicate the degree of antenna coupling that might be expected between the antennas for SIMOP operation. Explicit coupling analysis to determine voltages at passive antennas due to transmission on any one of the others will be presented in a subsequent paper. Thus the CEM analysis provides a special powerful “virtual antenna range” wherein individual performance and SIMOP antenna features can be determined. Validation of the results is based on previous CEM modeling and corresponding measurements, inter-code comparisons and the self-consistency of the results.

### 1.0 INTRODUCTION

Air fleets of many countries use the C-130/Hercules as a transportation work horse for a variety of domestic and international missions. It is a four-engine high wing STOL aircraft with distinctly large wings, a huge vertical stabilizer,



Figure 1 a) - Canadian C-130 Aircraft Landing in Darwin

and a swept tail-cone profile suited for its large cargo doors. Figure 1 a) shows this profile in the Canadian C-130 landing in Darwin Australia. The current configuration, labelled the C-130J, is likely to extend its lifetime for a few decades. Fig. 1 b) shows a United Kingdom version of the aircraft with its prominent “dorsal notch” antenna.

The HF radio, operating over the 2-30MHz band, plays an important role in long distance radio communications, especially in global scenarios. In addition, many aircraft have been equipped with HF Near Vertical Ionospheric Sounding Capability (NVIS), for short range operation at low altitudes over hilly terrain. It is important, for all these uses, to have essential technical data that would allow the prediction and analysis of the performance of this communications system.

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The EMC Laboratory first modelled the C-130 for NAWCAD in its multi-HF antenna configuration labelled the EC-130/TACAMO [1]. Subsequently the HF antenna coupling modes on the EC-130 were analyzed using NEC4 [2]. More recently, the Canadian DND C-130/Hercules was modernized to include the dorsal notch antenna shown in Figure 1b). A 933 wire segment model was used to analyze the performance of this antenna [3] with NEC4. The wire-grid model is shown in Figure 2. The results of the latter analysis are significant because they compared the numerical model results with measurements carried out by Lockheed-Marietta in the initial development program for the dorsal notch. In the same paper, some limited comparisons were also made with results using the MBC Galerkin code [4].

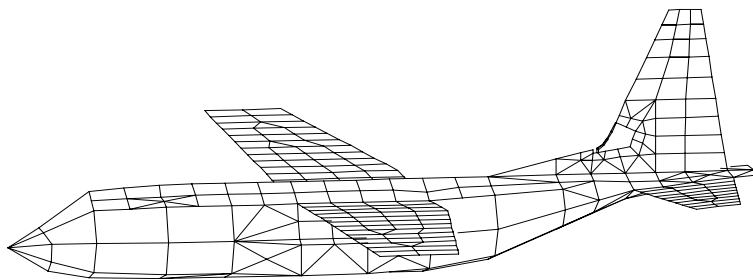
**Figure 1b) Model of the C-130J with Dorsal Notch Antenna**



Because of the importance of HF communications on aircraft of this type, there has been an interest in exploring multiple antenna configurations for HF SIMOP operation. SIMOP, as its acronym implies, involves the simultaneous HF transmission and reception on two distinct antennas. Since wire antennas are mainly supplanted by flush-mounted antennas, the candidate antennas are probes added to the vertical stabilizer and the wing tips, and dorsal and wing-notch antennas. With multiple antennas, the primary questions are: the individual antenna HF

communications performance, and then the assessment of the interaction of the antennas in the SIMOP mode. Of concern is the closeness in transmit frequency that can be tolerated without causing destructive interference to the SIMOP receiving system.

In this first paper, the 933 segment C-130/Hercules model is modified by the addition of wing tip probes and wing-root notch and of a tail probe antenna. As is customary, the models are considered to be in free space and the radiation



**Figure 2 –The 933 Segment Model of CC-130/Hercules Aircraft**

patterns, impedance and HF performance parameters<sup>1</sup> are computed over the 2 to 30 MHz HF frequency range in 0.1MHz increments. The results are also computed with the MBC Galerkin code under the same conditions. Thus in addition to the previous basic validation of the model by comparison with measured results, systematic inter-code comparisons are presented.

The model has a relatively sparse fuselage, but the upper aircraft surfaces are modeled with a finer mesh. The visual comparison of the dorsal notch in Fig 1 b) and Fig. 2 above shows the closeness of the detail that

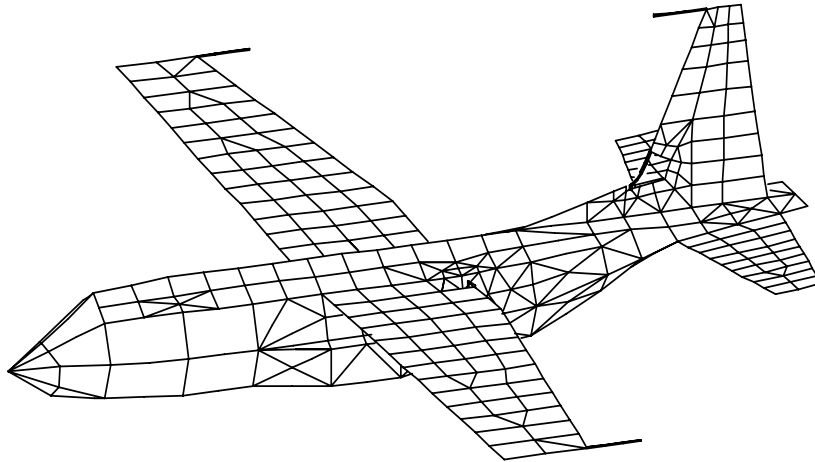
was modelled. Also evident in the detail of Fig. 2 are the original location points on the forward part of the fuselage for the wire antennas that had been used in earlier versions of the aircraft.

The changes to this basic model to create the model for SIMOP analysis are described below. This is followed by a presentation of the results of NEC4 and MBC code spectral sweeps that have been processed to produce comparative HF performance parameter plots.

<sup>1</sup> The HF performance parameters are radiation pattern efficiency, %E-theta and sub-%E-theta, and NVIS (or HVIS) and are defined in references [1] and [2].

## 2.0 MODELLING THE MULTIPLE HF ANTENNAS

As a basis for the analysis of HF SIMOP operation, the C-130 airframe and the wire grid model shown in Fig. 2 were opportune starting points. The dorsal notch had been well modeled, and it remained to construct the probe and wing-notch antenna feed points and antenna elements. These modifications are shown in Figure 3 a) and Fig 3 b).

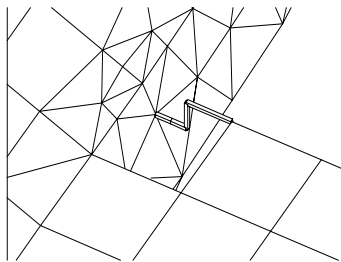


**Fig. 3a – C-130/Hercules SIMOP Model – Notch & Probe Antennas – 1002 Segments**

The probe antennas are modelled by adding a two meter wire onto the vertical stabilizer and the wingtips. Each is divided into three segments. The wing notch is a smaller version of the dorsal notch antenna that is adapted to the original wire grid pattern of the wing that is shown in Fig. 2. The detail of wing notch antenna and its feed area are shown in Figure 3 b).

The SIMOP model with all the antennas installed amounted to 1002 segments. The model was verified with the CHECK [5] software for conformance to known modeling guidelines for NEC. Models such as these have been shown to have sufficient bandwidth to produce credible results through the four-octave HF

frequency range [6]. The model was executed with NEC4 and the MBC code at 0.1MHz increments with each of the HF antennas excited in turn.



The EMC Laboratory Software system [7] allows us to access the solution file and process it for the display of radiation patterns, impedance, the HF Performance Parameters and the computed current distributions on the model.

The results from both computer codes are presented in the next section.

**Fig. 3 b) Wing Root Notch Detail – C-130 SIMOP Model**

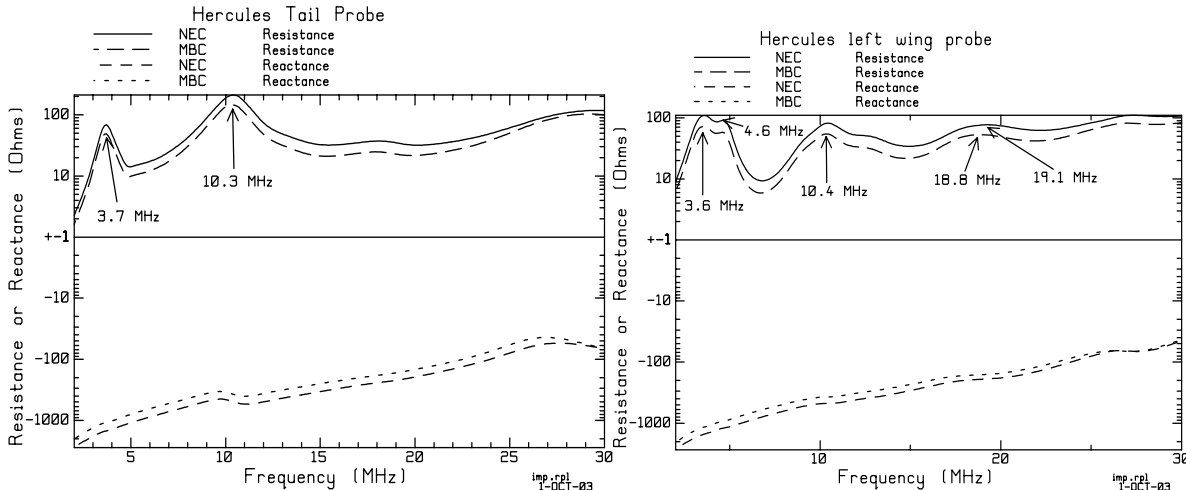
## 3.0 COMPUTED PARAMETERS OF THE HF SIMOP ANTENNAS

Careful computer modelling of aircraft antennas has been shown to provide a Virtual Modelling Range [3] that can provide radiation patterns and impedance results that match those available with scale-model radiation pattern and impedance models. In addition, the ability to view the computed current distributions provides a satisfying verification mechanism.

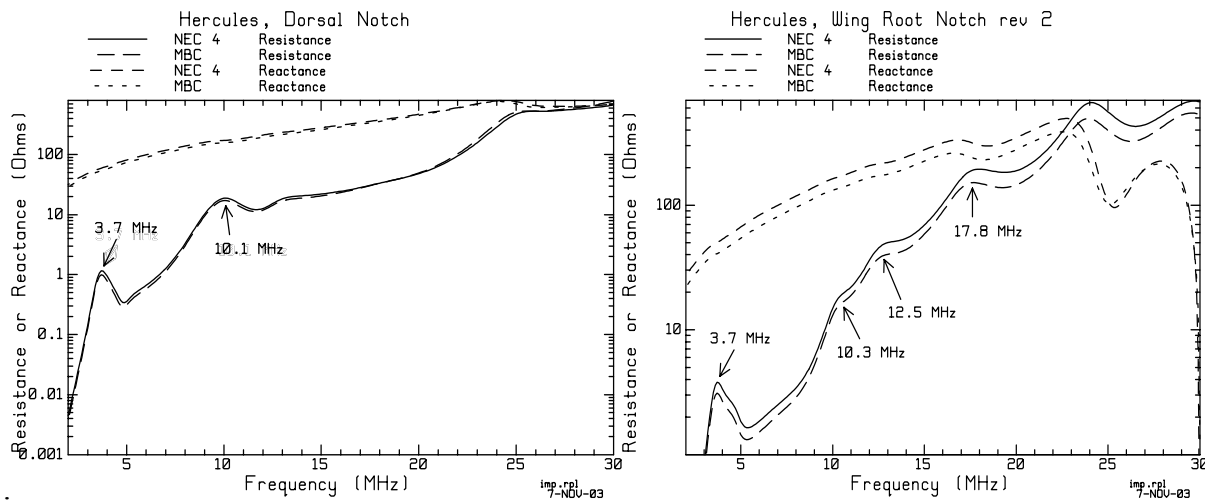
Recall that the HF Performance Parameters are numerical values at each frequency that correspond to the integration of the volumetric radiation patterns over sectors that have been shown to be important for certain communications modes – ground wave, ionospheric long range and Near Vertical Incidence (NVIS) propagation in Nap-of-Earth operation. The impedance vs. frequency is a basic meaningful parameter that is directly related to the power transfer efficiency of the HF antenna system with HF couplers that can tune these impedances over the HF frequency range.

### 3.1 Computed Impedance vs. Frequency – HF SIMOP Antennas

The computed impedances vs. frequency from both computer codes are shown in Fig. 4 a) for the probe antennas and in Fig. 4 b) for the notch antennas.



**Fig. 4 a) – Impedance Values for the Tail and Wing Probe Antennas**



**Fig. 4 b) - Impedance Values for the Dorsal and Wing-Notch Antennas**

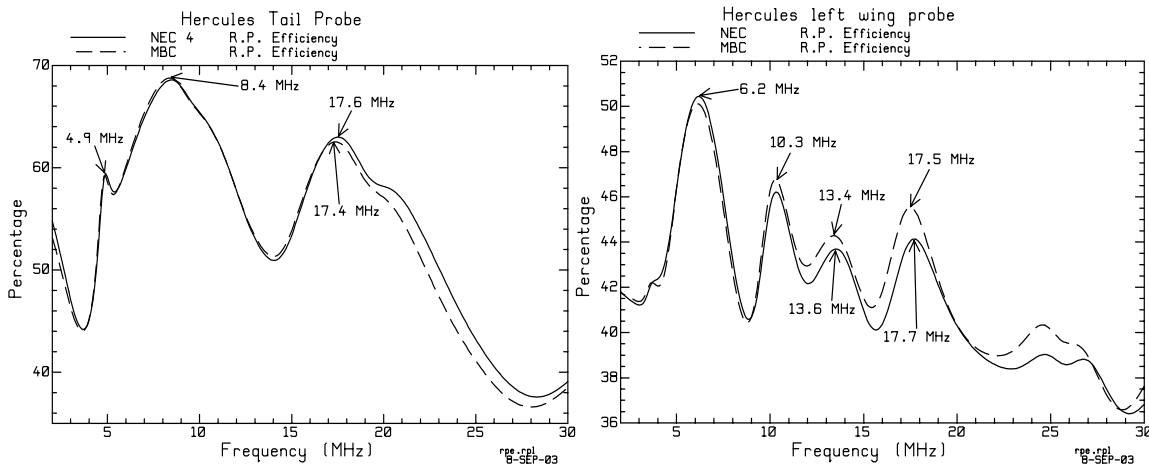
Dominant features of these curves that are of special interest are the negative reactance values of the probe and positive reactance values of the notch antennas that define the range of these values that must be ‘tuned’ by the commercial available automatic HF couplers. The closeness of the tracking of NEC4 and MBC results and the main differences are similar to those discussed the ACES 2003 paper on helicopter antennas [8]. Of particular interest are the peaks in the resistance values that are indicative of close coupling of the antennas to the airframe.

Note in particular the peaks at 3.7, 4.6 and 10.3 MHz. It will be expected that these are frequencies of very rapid change in radiation patterns with frequency and that, in addition, pattern differences between the antennas at these identical frequencies might occur. Previous work [8] has revealed that there might be other frequencies in addition to those shown in the resistance plots, where there are major variations in radiation pattern characteristics. These regions are defined and examined in the Performance Parameters and understood on the basis of current distributions on the model.

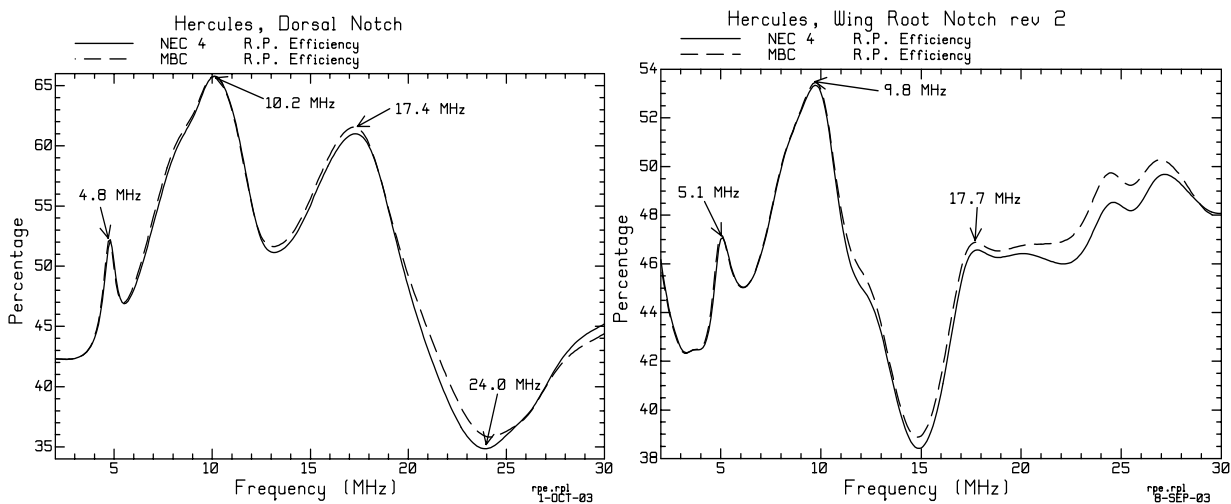
### 3.2 Computed Performance Parameters vs. Frequency – HF SIMOP Antennas

Recall that the four Performance Parameters that are important to HF performance are: radiation pattern efficiency, %E-theta, sub-%E-Theta, and NVIS vs. frequency.

Plots of the radiation pattern efficiency vs. frequency resulting from both computer codes are presented in Fig. 5a) for the probe antennas and in Fig. 5b) for the notch antennas.



**Fig. 5 a) Radiation Pattern Efficiency vs. Frequency – HF Probe Antennas**



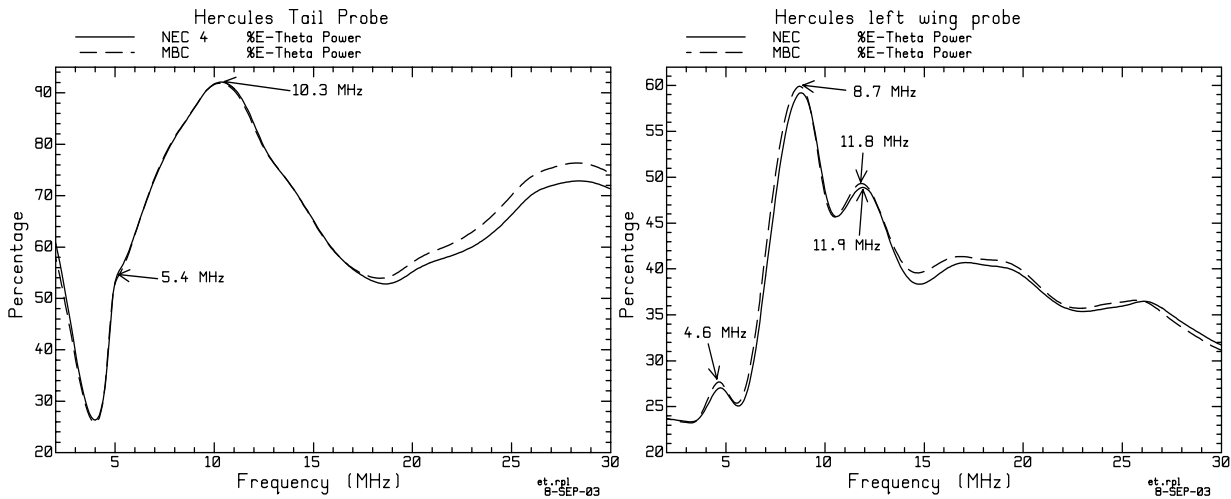
**Fig. 5 b) Radiation Pattern Efficiency vs. Frequency – Dorsal and Wing-Notch Antennas**

These curves produce a quantitative appreciation of the performance differences between the different antennas for long-range ionospheric communications. In developing scale-model techniques for aircraft antennas, Granger and Bohljahn [9] first produced such seminal comparisons in their work some five decades ago.

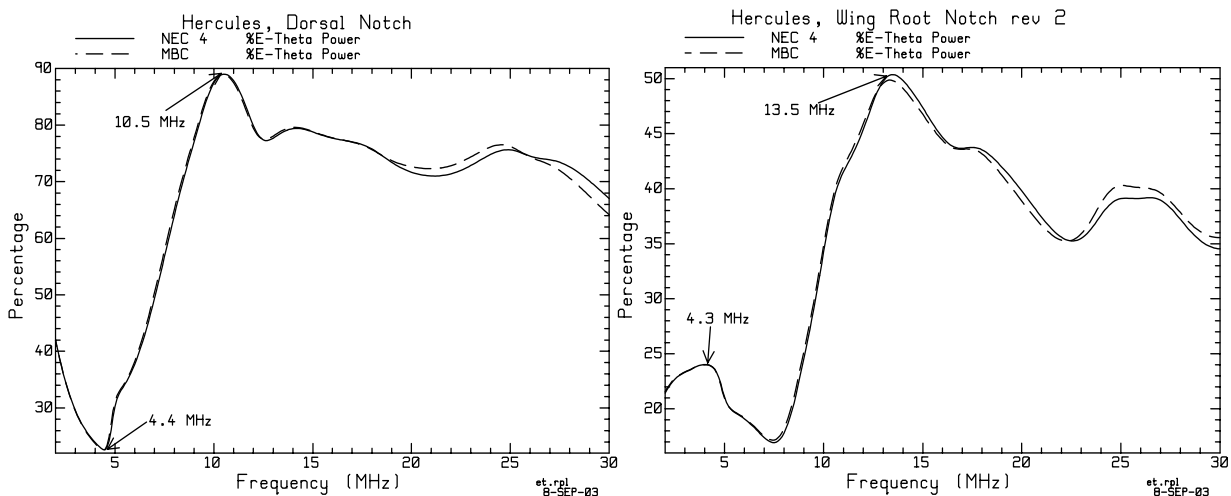
Notice also the labelled peaks in these plots, their similarities and differences to those seen in the impedance plots above. The closeness of the agreement in the results for both codes over most of the frequency range lends confidence in the modeling.

The plots of the remaining Performance Parameters will allow us further correlation of pattern changes, polarization differences and major spatial distributions.

The plots of %E-Theta vs. frequency for the probe antennas are shown in Fig.6a) and those for the notch antennas in Fig.6b).



**Fig. 6 a) - %E-Theta vs. Frequency – HF Probe Antennas**



**Fig. 6 b) %E-Theta vs. Frequency – HF Notch Antennas**

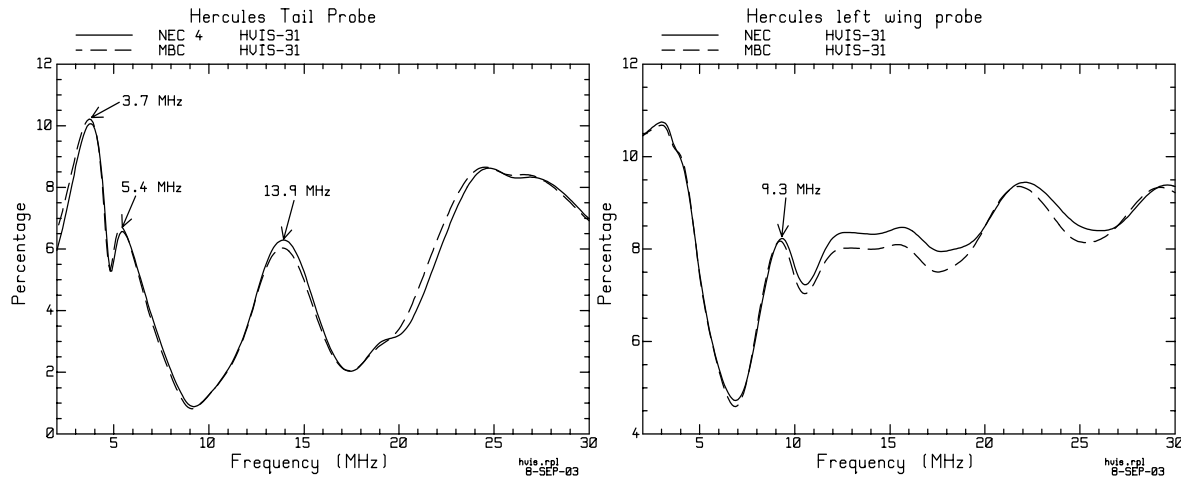
The sets of curves in Figures 6 (a) and 6 (b) allow the comparison of expected performance in the ground wave communications mode. The differences are substantial. At the same time, comparison with the radiation pattern efficiency results of Figures 5 (a) and 5 (b) reveals the extent that the radiation pattern efficiency curves are influenced by the vertical E-theta polarization alone.

It can also be seen that there are many differences in the peaks that occur in the radiation pattern efficiency plots and those in the %E-theta plots above. The additional power of the 'virtual range' that CEM provides is that it allows the ready comparison of these differences in radiation patterns and their understanding by examination of the associated current distributions.

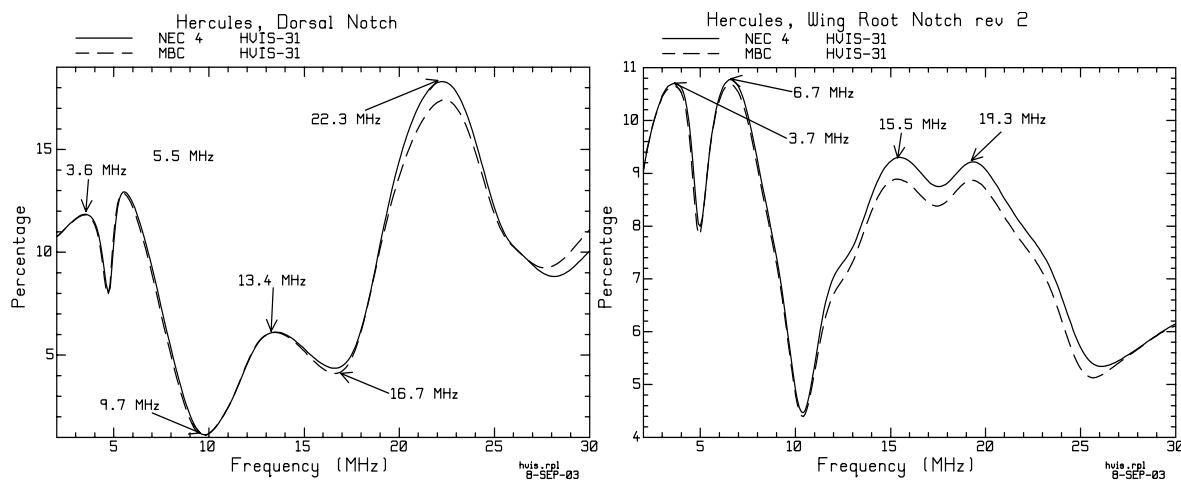
To conform to reasonable length requirements for the paper, the plots of Sub-%E-Theta vs. Frequency are being omitted. They will be shown in the oral presentation.

The NVIS parameter (also labelled as HVIS or high vertical incidence system) is important for NAP-of-EARTH (low altitude) operations. It quantifies the radiated power at high ionospheric incidence angles near the zenith, that have been found to be effective in ground wave propagation over irregular terrain.

The NVIS parameter vs. Frequency is plotted in Fig. 7 a) for the probe antennas and in Fig. 7 b) for the notch antennas.



**Fig. 7 a) – NVIS vs. Frequency – HF Probe Antennas**



**Fig. 7 b) – NVIS vs. Frequency – HF Notch Antennas**

The set of curves of Figures 7 (a) and 7 (b) allows the comparison of expected performance in the NVIS mode of communications for the various antennas. Such performance data has been added to the HF performance parameter set when NAP-of-EARTH communication studies demonstrated its importance for helicopters and low-flying aircraft.

Once more the differences can be appreciated in heretofore unavailable detail. A comparison with the radiation pattern efficiency plots of Figures 5 (a) and 5 (b) shows the complementarity of the two curve sets, because their volumetric sectors of integration are different -  $\pm 30$  degrees around the azimuth plane in the radiation pattern case and  $\pm 30$  degrees around the zenith in the NVIS case.



Of considerable interest once more, are the comparisons of peaks and nulls in this set of curves.

Noteworthy in all the three data sets above is the closeness of the values produced from NEC4 and from MBC spectral sweeps. For an appreciation of the nature of the current distributions on the model and the associated radiation patterns, a detailed comparison is shown in the next section for 3.7, 4.7 and 10.4 MHz. These will show the major differences that occur for the tail probe and wing probe antennas under study.

#### 4.0 RADIATION PATTERNS AND CURRENT DISTRIBUTIONS – SAMPLE FREQUENCIES

A frequency sampling of radiation patterns and current distributions is shown for the tail probe and for the wing probe in Figures 8 and Figure 9 respectively, in a three-dimensional format. The lobe structure and relative values of the two polarizations explain the variations in the performance parameter plots of Figures 5 to 7. Each figure shows the currents on the whole model, 3-D radiation patterns and current distributions near the feed region of the antenna.

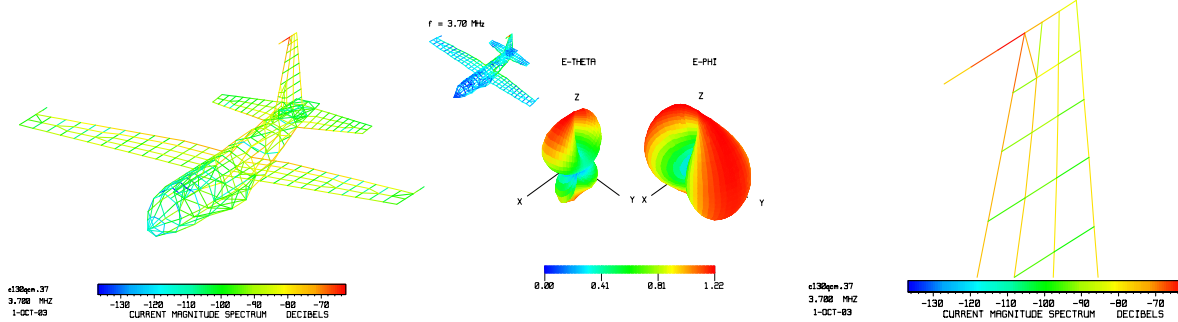


Fig. 8 a) Tail Probe – Currents and Radiation Patterns (MBC) – 3.7 MHz

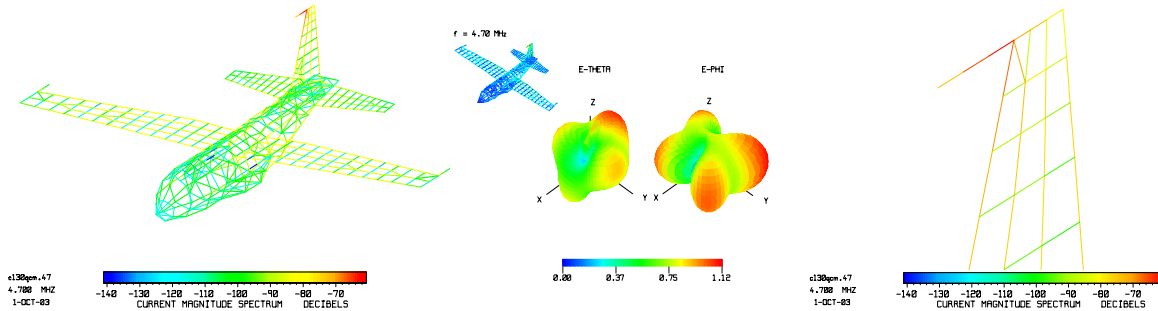


Fig. 8 b) Tail Probe – Currents and Radiation Patterns (MBC) – 4.7 MHz

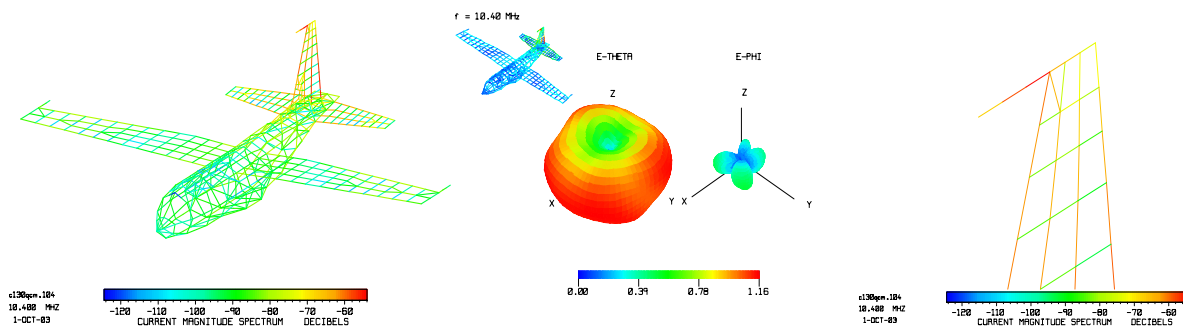
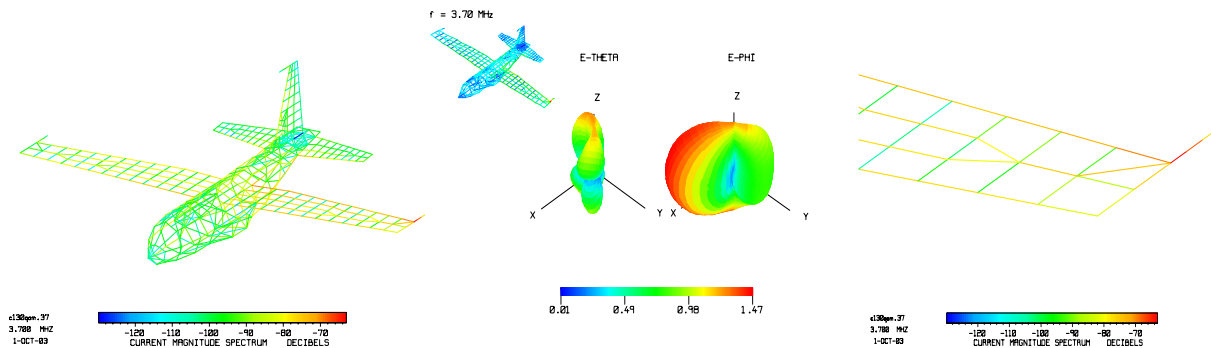


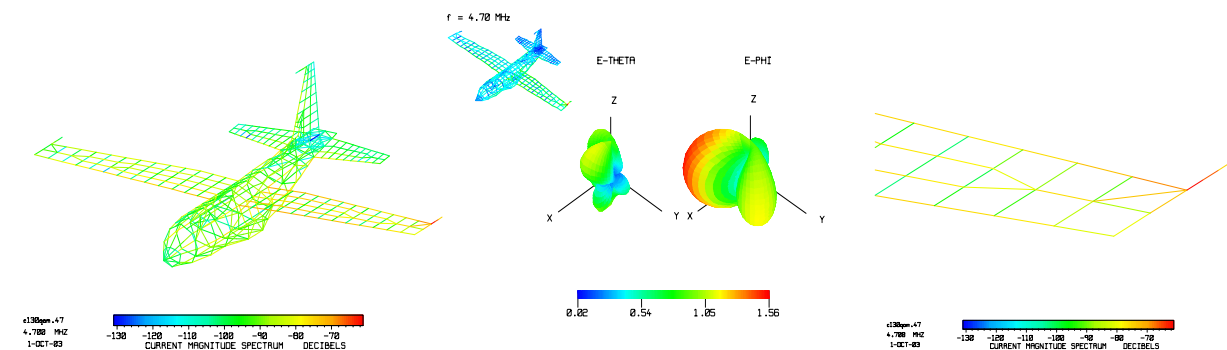
Fig. 8 c) Tail Probe – Currents and Radiation Patterns (MBC) – 10.4 MHz

It is of particular interest to note that the current distributions on the whole model shown in Fig. 8 a) begin to identify one of the resonant paths ( $\lambda/2$  at this frequency) on the aircraft: from horizontal stabilizer tip, along the fuselage and along the aft wing edge, on both sides of the aircraft. Such paths had been identified by Granger and Bohljahn [9].

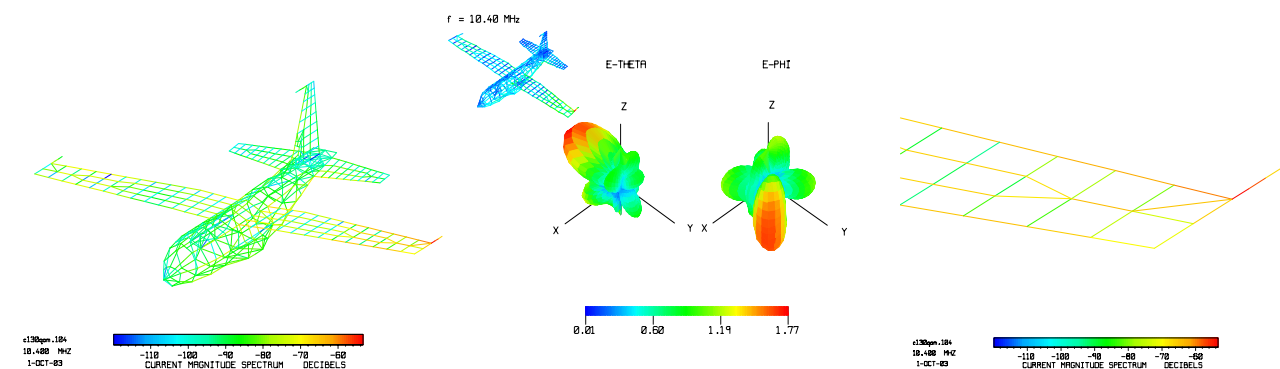
As an example of differences between the antennas, the currents and radiation patterns for the wing probe are shown in Figure 9 below.



**Fig. 9 a) Wing Probe – Currents and Radiation Patterns (MBC) – 3.7 MHz**



**Fig. 9 b) Wing Probe – Currents and Radiation Patterns (MBC) – 4.7 MHz**



**Fig. 9 c) Wing Probe – Currents and Radiation Patterns (MBC) – 10.4MHz**

The oral presentation will present dynamic movie-like plots of current distributions and 3-D patterns, swept over the entire frequency range. In such displays, other classic resonant paths are evident. Coupling to these resonant paths by

the antennas under study has been found to be fundamental to their coupling to each other and their expected behaviour in the HF SIMOP mode.

## 5.0 COMMENTARY

It has been shown that complex aircraft models can produce complete HF performance data on antennas such as tail and wing probes and dorsal and wing-root notch antennas. This vast data set of radiation patterns, impedance and current distributions can be mined for explicit details over any portion of the frequency range and for an understanding of the wide radiation pattern variations that are evident. The reliability of the data is reinforced by the NEC4 and MBC code comparisons and the initial comparisons with scale-model measurements that had been carried out on the C-130/Hercules dorsal notch development.

The closeness of the results of NEC4 and MBC and the nature of the differences are similar to that discussed more extensively in previous work on helicopter antennas [8].

Peaks in the plots of antenna resistance and those in the Performance Parameters are indicative of coupling of the antennas to the airframe. The current distributions at these frequencies explain this phenomenon by showing the excitation of classic resonant paths on the aircraft [9].

It is anticipated that a close study of the resonant paths and frequencies for each of the antennas will be a sound basis for the understanding of the antenna/antenna coupling that would result in HF SIMOP operation. Loading passive antenna terminals with 50 ohms while a selected antenna is excited [1], will allow the plotting of coupled voltages to the receiver terminals and the computation of coupling coefficients between the antennas. This second portion of the study has been initiated and will be reported in a forthcoming conference.

## Acknowledgments

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